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ORIGINAL ARTICLE

Assessment of coal mine water in Moatize by static and leaching tests

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Abstract Acid mine drainage (AMD) is one of the most serious environmental problems in mining worldwide. One of the largest unexploited coal basins in the world is located in Moatize. It contains about 23 billion metric tonnes of coal. The coal mining there is done in riparian sections of the Zambezi River basin, making it particularly vulnerable to pollution. Much of the coal waste is produced by a number of multinational mining companies operating in the area. Accordingly, it was of clear interest to investigate the possibility that AMD was being generated there. Coal waste and pit water were collected randomly from different piles and pits in two mines in Moatize. Both static and kinetic tests were performed. It was found that AMD could be generated in one of the two mines that were studied. The mine drainage obtained from both coal mines was found to be of neutral pH and to have a high content of sulfates, calcium, magnesium, and manganese.

Keywords Acid mine drainage · Static and kinetic test · Coal mine drainage · Moatize coal mine

Introduction

Coal mining in Mozambique has increased rapidly in the last 10 years, due to the discovery of new coal mine deposits in the Tete province. In 2008, it was found that one of the largest unexploited coal basins in the world, with an estimated capacity of about 23 billion metric tonnes of coal, is in the Moatize district in the Tete Province (Kirshner and Power 2015). In 2010, such multinational companies as Vale Mozambique (from Brazil), Rio Tinto (Anglo-Australian), Jindal Steel and Power (Indian), Coal and Beacon Hill (The UK), Eurasian Natural Resources Corporation (Kazakhstan), and Minas de Revubué (Anglo-American) became established in the Tete Province to exploit coal (Kirshner and Power 2015). Coal mining in Mozambique is being carried out in the riparian area of the Zambezi river basin in Moatize, possibly making it susceptible to pollution. The water of the Zambezi River basin is essential for aquatic life as well as for people living in the riparian area who use it for agriculture, fishing, and as a source of drinking water.

Acid mine drainage (AMD) is an environmental problem that coal mining commonly creates. It develops through the sulfides that are found in the minerals that are coming in contact with water and oxygen, this resulting in ferric hydroxide [$Fe(OH)_3$] and sulfuric acid (H_2SO_4) being generated. If the carbonates and silicates present in minerals do not have enough capacity to neutralize the generated acid, it becomes AMD. This resulting in low pH, high acidity, and high concentrations of metals and sulfate (Plante et al. 2012). The $Fe(OH)_3$ produced precipitates in the river bed, giving the water reddish/yellowish color.

Since it was not known how likely it was that the coal mining in Moatize was generating AMD, it was regarded as important to investigate both that and what other types of pollution of water resources take place in that area.

Static and kinetic tests can be used to predict both the possibilities for mine drainage generation being carried out and the quality of it one can expect to achieve (Banerjee 2014). Static test can be carried out prior to kinetic test so

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as to assess the balance between components that produce acids and those that consume them (Coastech Research INC 1991). There are a number of methods reported in the literature for predicting AMD generation, one of these, the so called acid–base accounting (ABA) or Sobek method is based on determining the acid potential (AP) and neutralizing potential (NP) of mine waste. When AP and NP are known, the net neutralizing potential (NNP) can be calculated on the basis of the difference between NP and AP (Bouzahzah et al. 2014). The waste material can then be characterized as either non-acid producing or acid consuming if NNP > 20 $kgCaCO_3$/tonne, and as acid producing if NNP < −20 $kgCaCO_3$/tonne. There is a zone of uncertainty between −20 $kgCaCO_3$/tonne < NNP < 20 $kgCaCO_3$/tonne in which nothing can be said, this being a critical zone (Bouzahzah et al. 2014).

The neutralizing potential ratio (NPR = NP/AP) is another parameter that can be used to assess whether waste material is acid or non-acid producing. For NPR values greater than 4:1, waste materials are characterized as non-acid producing, whereas for NPR values of between 2:1 and 4:1, AMD is not expected to occur. For NPR values between 2:1 and 1:1, AMD is expected to be generated. When NPR is less than 1, the material is considered to be acid producing (Price et al. 1997).

Acid generation for each coal mine is site-specific, meaning that to develop a plan for managing or treating AMD, it is necessary to develop a site-specific study so as to determine the behavior of the mine waste over time (Devasahayam 2006). There are only very limited studies of the prediction of AMD generation in Moatize reported in the literature.

The aim of the present paper is to investigate the possibilities of AMD being generated in Moatize. If the possibility of AMD generation occurring is found to be unlikely, neutral drainage with heavy metals and neutral drainage with sulfate generation will be evaluated.

Study area

Moatize is a district of theTete province that is situated in the center of Mozambique (Fig. 1). It is 20 km from Tete city and has a total surface about 8.455 km^2 in size and a population density of 13.4 pop/km^2. Its climate is semi-arid and sub-tropical, its having an annual mean precipitation and a potential evapotranspiration of 644 mm and of 1.626 mm/year, respectively. The maximum and the minimum average temperatures per year are 33 and 21 °C, respectively (José and Sampaio 2011). The Moatize-Minjova coal basin is the only one there that is currently open to exploitation. This basin is a karoo-aged rift, its consisting of interbedded carbonaceous mudstones and sandstones, together with coal seams (Fernandes et al. 2015).

The coal mining waste analyzed in the study was taken from a waste pile produced by two different mining companies that are operating in the Moatize mining field. This particular study area was selected, because it contains one of the largest unexploited deposits of mineral coal of the world, in an area that the Zambezi River and various tributaries of it run through. The area in question is potentially sensitive to pollution due to the mining activities there, despite the large flow of water in the Zambezi River (Fig. 1). The tributaries of the river are of particular interest here, due to the considerably lower flows compared to the Zambezi River.

Methods

The methods employed involve collecting samples from two mining companies denoted as M and R, followed by the analysis of pit water and of a waste rock pile to determine their composition. The laboratory experiments carried out include static and kinetic tests performed in the water resources laboratory of Lund University, using Buchner funnels at 33 °C. Analysis of the mine water and that of the waste rock were performed in the laboratory of instrumental chemistry at the Biology Department of Lund University.

Sampling

The waste samples involved were collected from waste piles produced by the mining companies (Fig. 2). The mining process includes the digging of one or more pits to exploit the resources involved and the storage of waste in piles close to the pits. Once mining is finished in a given pit, the waste is returned to the pit for backfilling. The waste samples used for the analysis were prepared by taking various quantities of waste from different piles that were selected randomly and in each case were mixed thoroughly by a shovel so as to obtain a fraction about 300 kg.

Water samples were collected from different pits (Fig. 2) using plastic bottles of 500 ml and these samples were taken for laboratory tests. The samples of mine water and of coal waste were taken from two different coal mines. The name of the mining companies involved is not discussed at their request.

Static test

During the static test, three different methods were employed: paste pH testing, standard acid–base accounting (ABA) (Sobek 1978), and modified acid–base accounting (Coastech

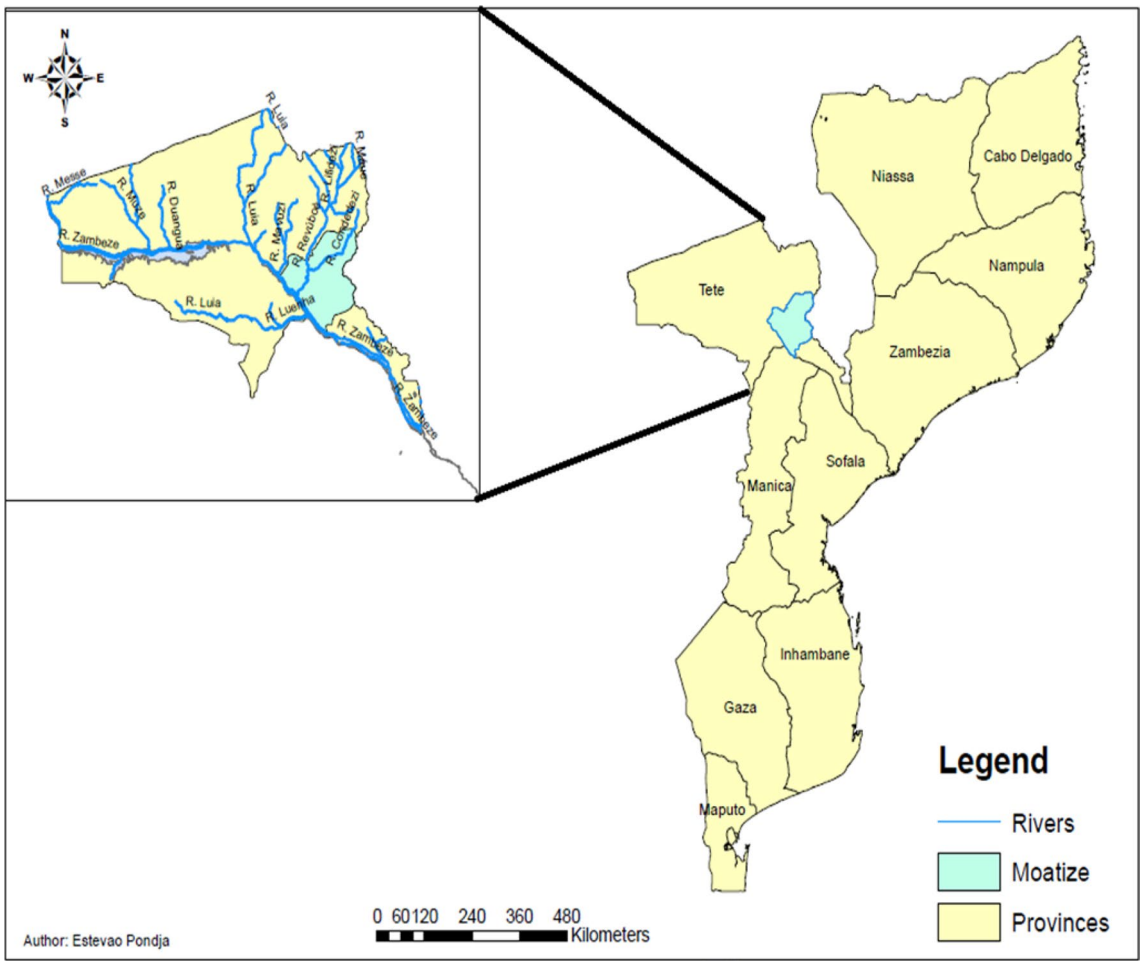

Fig. 1 Map of Mozambique and of theTete province there showing Moatize and various tributaries of the Zambezi River

Fig. 2 Coal mine in Moatize

Research INC 1991). For the paste pH test, 10 g of waste sample sieved to an average particle size less than 0.25 mm was mixed with 5 ml of deionized water in a beaker to form a consistent pulp. The pulp was thoroughly mixed using a spoon, and the pH was measured using pH meter.

For the standard acid–base accounting method, waste coal sieved to an average particle size less than 0.25 mm was analyzed in the laboratory for determining its chemical composition with respect to Fe, Mn, Al, Ca, Mg, Zn, Ti, Ni, total sulfur, and sulfur from organic compounds.

A sample about 0.5 g in was placed in a piece of aluminum foil and two drops of 25% HCl were added. Bubbling of the sample indicated a reaction between carbonates contained in the waste sample and the added acid. The reaction rates obtained using the fizz rate test are shown in Table 1.

A 2.0 g sample with an average particle size of less than 0.250 mm was poured into an Erlenmeyer flask, HCl being added in accordance with the volumes and strengths of the fizz test that results indicated. The pulp obtained was heated then, and swirling produced by use of the magnetic stirrer was continued until the reaction was completed. Deionized water was added to produce a total volume of 125 ml, and the resulting mixture being boiled for 1 min. Once cooled, the sample was titrated with NaOH, using the volume and strength determined by use of the acid fizz test until a pH of 7.0 was reached. The volume of NaOH added was recorded and was used to determine the neutralizing potential of the sample according to Eq. 1:

$$\mathrm{NP(kgCaCO_3}/t) = \frac{[(\mathrm{N} \times \mathrm{vol(ml)\,of\,HCl}) - (N \times \mathrm{vol(ml)\,of\,NaOH})) \times 50]}{\left[\mathrm{Sampleweight(g)}\right]} \quad (1)$$

where: N_{ac} is the normality of the HCl used for digestion, N_{bas} is the normality of the NaOH used for titration, and vol is the volume of each solution (ml).

The acid potential (AP) was calculated using Eq. 2 for the standard method

$$\mathrm{AP} = 31.25 \times \%S_{\mathrm{total}}, \quad (2)$$

Table 1 Volumes and concentrations of HCl during the fizz rate test

Fizz rating	Volume of HCl (ml)	Strength of the acid (normality)
None	20	0.1
Slight	40	0.1
Moderate	40	0.5
Strong	80	0.5

where S_{total} is the total sulfur in percentage and AP is the acid potential in kilogram of $CaCO_3$ per tonnes of the material.

The modified acid–base account was made by first performing the fizz test and then analyzing the AP of the waste sample. In doing so, 2.0 g of waste sample with average particle size of less than 0.074 mm was poured into a 250 ml Erlenmeyer flask, HCl being added then in accordance with the volumes and strengths obtained on the basis of the fizz test results. The resulting sample was agitated and was let to settle for 24 h then after which the pH was checked to determine whether it fell between 1.5 and 2.0. If so, the sample was titrated with NaOH until pH 8.3 was reached. Otherwise, the experiment had to be repeated. For positive samples, the volume of NaOH was recorded. The NP and AP were calculated using Eq. (1) and Eq. (3), respectively:

$$\mathrm{AP} = 31.25 \times \%S_{\mathrm{sulfide}}, \quad (3)$$

where S_{sulfide} is the percentage of sulfur in the sample. S_{sulfide} was calculated then using Eq. (4), (Plante et al. 2012):

$$wt\%S_{\mathrm{sulfide}} = wt\%S_{\mathrm{total}} - wt\%S_{\mathrm{sulfate}}. \quad (4)$$

Kinetic test

The kinetic test was performed using a column test described in the ARD test handbook (Smart et al. 2002).

In connection with the experiments, use was made of four Buchner funnels 110 mm in diameter made of polypropylene as well as filter paper, 1 l collection containers, heat lamps, and deionized water. After preparing the setup, as shown in (Smart et al. 2002), filter paper was placed at the base of each of funnels. The weight of the funnels and their filters was measured and 0.5 kg of the sample that was less than 4 mm in average size was loaded into each of the funnels. Two such samples for each of the two mining companies were tested.

The heat lamps were operated continuously 5 days a week, the samples being left unheated then for two consecutive days. The temperature on the surface of the funnels was kept at a constant level of 33 °C through use of heating lamps.

Deionized water was used as the test solution. During the experiments, 50 ml of it was applied to the surface of each funnel once a week. The test solution was added on day 5. During days 6 and 7, the heating lamps were kept at OFF. The leachates were collected on day 1 of each week

Table 2 Chemical composition of a coal waste pile obtained in Moatize (< 1 mm) in wt %

Elements	M	R
Fe	1.2	1.0
Mn	0.0211	0.0144
Al	1.9	3.2
Ca	2.4	0.26
Mg	1.0	0.29
Zn	0.0030	0.0059
Ti	0.0110	0.0160
Ni	0.0008	0.0013
S_{total}	**1.1**	**0.69**
$S_{sulfate}$	0.116	0.017
$S_{sulfide}$	**0.984**	**0.673**

Table 3 Results of the static test (NP, AP, and NNP are in $kgCaCO_3$/tonnes waste)

Sample	NP	AP	NNP	NPR	Paste pH
Standard method					
M	133.33	34.38	98.95	3.88	6.0
R	6.25	21.56	−15.31	0.29	7.5
Modified method					
M	82.5	30.75	51.75	2.68	6.0
R	9.87	21.03	−11.16	0.47	7.5

and were sent to a laboratory for analysis. The calculations and plots for the kinetic test followed procedures recommended by EPA (EPA 2011).

Water and coal waste analysis

The metals were analyzed using ICP-OES, Optima 8300 from Perkin Elmer. A 1% concentrated nitric acid solution was added to the water samples prior to analysis. The coal samples were dissolved in 7 ml of nitric acid and 3 ml of H_2O, using the microwave MARS 5 from CEM, the resulting solution being diluted then to a volume of up to 50 ml and analyzed by use of ICP-OES. The conductivity was measured using the conductivity meter CDM 92 from Radiometer Copenhagen. The sulfate was analyzed using 861 advanced compact ion chromatography from Metrohm. Alkalinity was analyzed using TOC-V(cph) from Shimadzu.

Results and discussion

The chemical composition of the samples M and R from the two respective coal mines that were studied is presented in Table 2. Sample M has more sulfur than sample R, which means that the AP for sample M is probably higher than that for sample R. The sulfide sulfur was determined in accordance with Eq. (4).

The results of the static test are presented in Table 3. The standard and the modified methods show that for the M samples, NNP is higher than 20 $kgCaCO_3$/tonne, which means that there is unlikely to have been AMD generation in the mine in which the M samples were collected. The NNP value of M samples obtained using the standard method was higher than those obtained using the modified method. This probably occurs because of there being an overestimation of NP with use of the standard method, due to boiling of the pulp during determination of the NP. The paste pH test for M samples is 6. Nothing can be said about M samples using the value of paste pH. Results of the ABA test are in contradiction to those of the paste pH test. The kinetic test (leaching test) can be used to clarify the contradiction between results of the ABA test and the paste pH test. The NNP value obtained using both the standard method and the modified method for R samples falls in the uncertainty zone (-20 $kgCaCO_3$/tonne $<$ NNP $<$ 20 $kgCaCO_3$/tonne).This means that nothing can be concluded regarding the possibility of AMD generation there. A paste pH test indicates that pH = 7.5, which means that reactive carbonates are present in the sample. In this case, the kinetic test can be used to obtain more information about the R samples so as to help to clarify the assessment.

The NPR for M samples is between 2 and 4, which means that AMD generation is not to be expected. The NPR for R sample is less than 1, which means that the coal waste can be considered acid producing.

Due to the results lying within the uncertainty zone and there being contradictory results for the paste pH test, for the NNP interpretation and for NRP, the kinetic test can be performed instead to obtain the details that are needed.

Mine water from pits

Table 4 shows the results of analysis of the mine water collected from four different pits. M1, M2, and M3 are all results for the same mine company, whereas R1 are results for another mining company. It was not possible to collect further samples for mining company R, since the pits were dry. From the results obtained, it can be seen that the mine water is neutral and has a high content of sulfate, calcium, and magnesium, which is an indication of neutralization of the acid by carbonates and silicates.

Moatize has many coal mining companies. The cumulative effect of the operations of those mining companies located along small tributaries of the Zambezi River could very well result in significant water pollution characterized by a high level of hardness and a high content of sulfate.

Table 4 Composition of water in the pits coming from groundwater during mining activities

Elements	Samples			
	M1	M2	M3	R1
Al (mg/l)	0	0	0	0.028
Ca (mg/l)	331	119	430	338
Fe (mg/l)	0.131	0.057	0.042	0.046
Mg (mg/l)	240	242	407	498
Mn (mg/l)	0	0	0.003	1.4
Ni (mg/l)	0.001	0	0	0.017
S (mg/l)	943	620	1156	1141
Ti (mg/l)	0.0003	0	0	0
Zn (mg/l)	0.001	0	0.001	0.057
SO_4^{2-} (mg/l)	3154	2028	3812	3594
pH	8.2	8.5	8.1	7.7
Conductivity (μS/cm)	8.4	6.7	11.9	13.7
Alkalinity (mmol/l)	3.8	4.2	2.4	3.1

Kinetic test results

The results of the leaching test are presented for both samples in Tables 5 and 6. The cumulative concentrations of SO_4^{2-}, Ca, Mg, and Mn for all 11 weeks for both samples are high as compared with the safety limits provided by EPA and WHO. High concentrations of Ca and Mg can be explained in terms of the high weathering rates of carbonates and of silicates.

The resulting drainages from samples for mining companies M and R are neutral with high concentration of sulfates and of metals.

The pH values for the two samples are presented in Tables 5 and 6, all of them being greater than 7.1 and less than 7.8.These values are thus in nearly neutral to alkaline region. The presence of Fe can be indicative of the acid being both generated and neutralized by the large amounts of neutralizing species that are present.

The cumulative sulfate in both samples is shown in Fig. 3. The sulfate rate in the sample from mine M is higher than that in the sample from mine R, which means that the oxidation in the sample from mine M occurs at a faster rate than in the sample from mine R.

Tables 5 and 6 show how the concentrations of Fe, Al, and Mn vary over time in both samples. The concentration of Mn is much higher than that of Fe and of Al. In Table 2, one can see that the Mn content in the samples is less than that of Fe and Al. The high concentration of Mn can be explained in terms of high weathering rate of minerals that contain Mn, as compared with that of those that contain Al and Fe. The Mn concentration in a sample from mining company R shows a positive trend, whereas in the sample from mining company M increases in the first few weeks and decreases then until week 11 (Tables 5, 6).

The cumulative flux of Mg^{2+}, and Ca^{2+} and its sum in the $CaCO_3$ equivalent are presented in Figs. 4 and 5. The sum of the cumulative flux of Mg^{2+} and Ca^{2+} depends mainly upon the flux of Mg^{2+}, which means that calcium has a low impact upon the neutralization process of AMD. This means that the dissolution of dolomite [$CaMg(CO_3)_2$] and magnesite ($MgCO_3$) is higher than the dissolution of calcite ($CaCO_3$).

Figures 6, 7 show the cumulative oxidation products, the sulfates as compared with the carbonate dissolution

Table 5 Analysis of the leachates from sample M

Week	pH	EC (mS/m)	mg/l							
			SO_4^{2-}	Ca	Mg	Fe	Al	Mn	Hg	Zn
1	7.350	10.100	60.500	11.450	8.300	0.086	0.083	0.257	0.008	0.006
2	7.450	25.400	266.500	31.800	38.800	0.065	0.084	1.102	0.007	0.003
3	7.300	128.000	655.000	65.000	114.500	0.123	0.105	2.406	0.007	0.006
4	7.450	117.500	649.000	77.000	106.500	0.076	0.102	1.694	0.005	0.008
5	7.350	174.500	815.500	55.500	201.000	0.100	0.136	2.308	0.007	0.008
6	7.600	71.500	342.000	40.500	64.000	0.317	0.028	0.833	0.007	0.002
7	7.650	107.000	533.000	57.000	109.500	0.078	0.028	1.314	0.000	0.006
8	7.200	174.500	733.000	90.500	141.000	0.074	0.018	1.523	0.007	0.007
9	7.550	120.000	658.000	70.500	113.500	0.021	0.014	1.058	0.005	0.004
10	7.500	151.500	812.000	65.500	158.500	0.056	0.043	1.285	0.018	0.006
11	7.200	218.500	1151.500	110.500	119.000	0.066	0.000	1.910	0.018	0.023
Mean	7.418	118.046	606.909	61.386	106.782	0.096	0.058	1.426	0.008	0.007
Std	0.152	63.413	299.136	27.342	53.977	0.077	0.045	0.636	0.005	0.006
Cumulative		1298.500	6676.000	675.250	1174.600	1.060	0.638	15.689	0.087	0.075
Max	7.650	218.500	1151.500	110.500	201.000	0.317	0.136	2.406	0.018	0.023
Min	7.200	10.100	60.500	11.450	8.300	0.021	0.000	0.257	0.000	0.002

Table 6 Analysis of the leachates from sample R

Week	pH	EC (mS/m)	mg/l							
			SO_4^{2-}	Ca	Mg	Fe	Al	Mn	Hg	Zn
1	7.300	15.800	28.500	5.250	3.300	0.148	0.369	0.106	0.011	0.009
2	7.350	56.100	91.000	11.600	8.250	0.147	0.577	0.214	0.006	0.002
3	7.550	41.000	233.000	16.500	15.000	0.122	0.293	0.255	0.010	0.000
4	7.500	51.000	238.000	16.500	23.000	0.072	0.261	0.310	0.007	0.001
5	7.450	61.500	327.500	19.500	30.000	0.055	0.203	0.385	0.002	0.004
6	7.750	89.500	427.500	35.000	72.000	0.099	0.025	0.603	0.006	0.003
7	7.450	75.500	386.000	28.500	44.000	0.044	0.118	0.561	0.000	0.006
8	7.550	181.000	758.500	85.500	133.500	0.034	0.014	1.579	0.006	0.013
9	7.500	191.500	757.500	90.000	134.000	0.019	0.034	1.677	0.007	0.015
10	7.600	255.000	1173.000	140.500	195.000	0.033	0.123	2.430	0.021	0.026
11	7.250	218.500	1070.500	123.500	119.000	0.025	0.000	1.990	0.013	0.020
Mean	7.477	112.400	499.182	52.032	70.641	0.072	0.183	0.919	0.008	0.009
Median	7.500	75.500	386.000	28.500	44.000	0.055	0.123	0.561	0.007	0.006
Std	0.142	82.705	385.883	48.730	64.750	0.049	0.180	0.832	0.006	0.008
Cumulative		1236.400	5491.000	572.350	777.050	0.795	2.016	10.108	0.086	0.097
Max	7.750	255.000	1173.000	140.500	195.000	0.148	0.577	2.430	0.021	0.026
Min	7.250	15.800	28.500	5.250	3.300	0.019	0.000	0.106	0.000	0.000

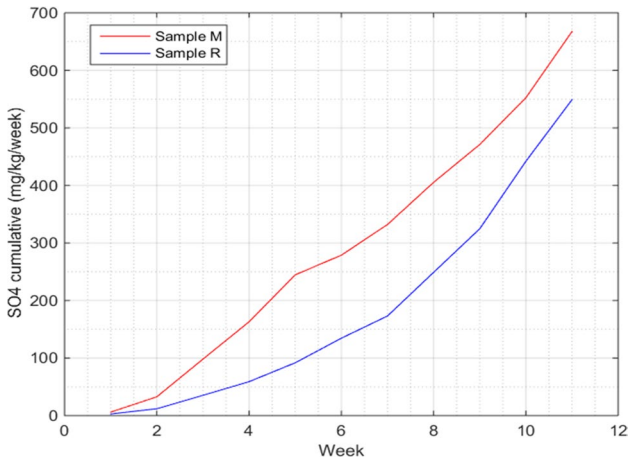

Fig. 3 Cumulative sulfates present in the course of the kinetic test

products, as well as calcium and magnesium, in the leachate. These figures show the geochemical evolution of the acidic and the neutralization potential in the course of the kinetic test. The linear relationship between the oxidation and the dissolution products indicates that the neutralization is a direct response to the acid that is produced. The slope represents the neutralization rates. The neutralization rates of the samples from both mining companies are constant and the neutralization rate of the samples from the mining company M is higher than the neutralization rate of the sample from mining company R.

Figure 8 shows that the weathering rate of the carbonate is higher at the beginning, but that it slows down from week 4 on for the samples from the mining company M. The material that becomes exhausted first is sulfur, which means that very likely the AMD that is produced will be neutralized. The results of the static test show that the NNP of the samples from the mining company M were above 20 $kgCaCO_3$/tonne of waste, which means that the generation of AMD is unlikely. The NPR ratio is between 2 and 5, meaning that AMD is not expected to occur. The paste taste shows a pH value of 6, which means that nothing can be said about the possibility of AMD generation. The results of the kinetic test confirm the results of the static test in indicating that AMD led to the conclusion that there is unluckily to be AMD generation from the tailing of mining company M.

Figure 9 shows the weathering percentage of sulfur and of carbonates present in the sample from mining company R. The weathering rate of the carbonate is high, which means that the material that will be exhausted first is the carbonate. Once the carbonate is used up, AMD can be produced. According to the results of the static test performed on the sample from mining company R, NNP is located in the uncertainty zone, which means that nothing can be said about AMD generation. NPR is less than one, which means that the sample from the mining company R can be considered to be an acid producing material, although the results of the paste test say that the pH value is around 7.5. The paste test probably gives this result because of the carbonate neutralizing all of the acid that is generated, but it does not take into account what will happen when all of the carbonates that are neutralizing the acid are exhausted. Detailed studies are needed to obtain more consistent information concerning the possibility of AMD generation in

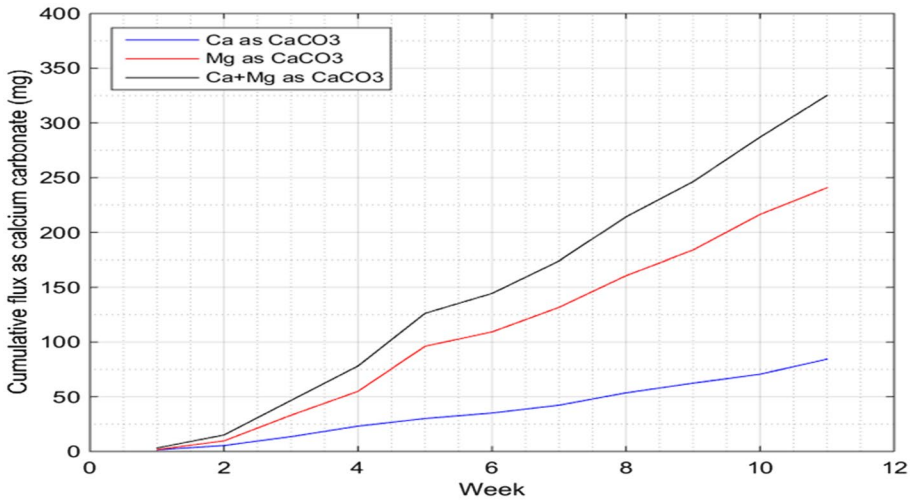

Fig. 4 Cumulative load of Ca+Mg in $CaCO_3$ for sample M

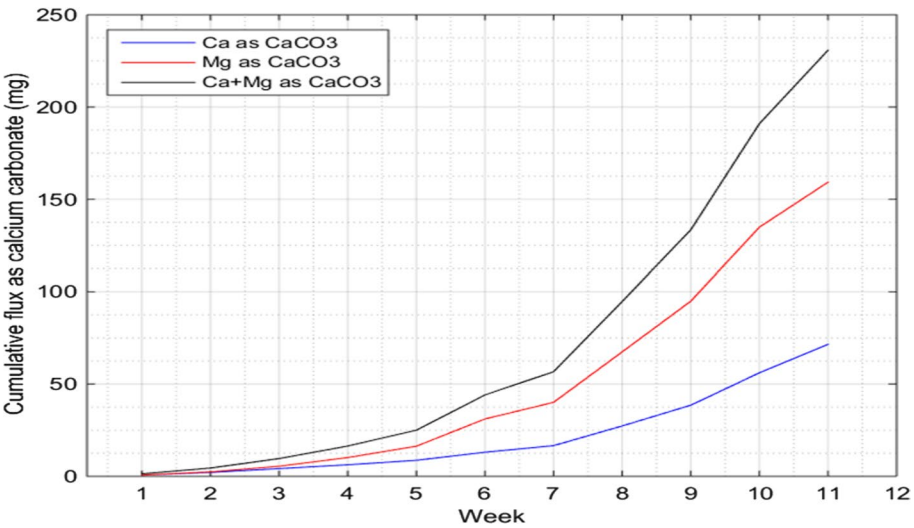

Fig. 5 Cumulative load of Ca+Mg in $CaCO_3$ for sample R

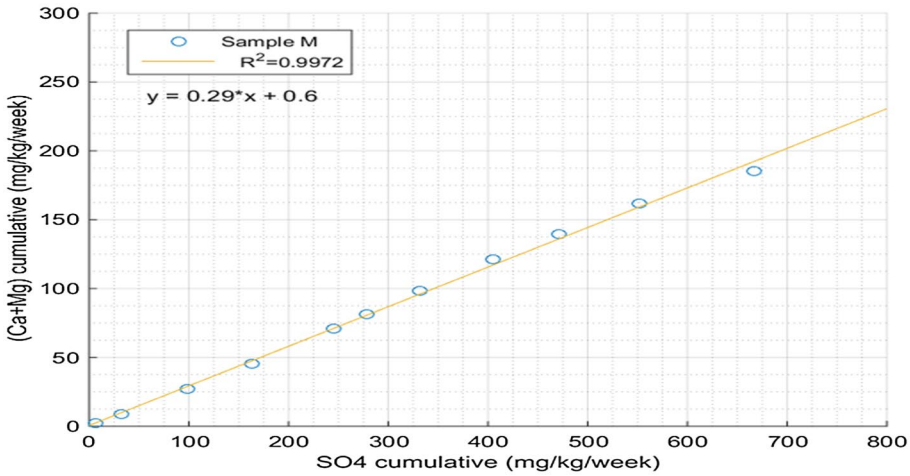

Fig. 6 Oxidation–neutralization curve for sample M

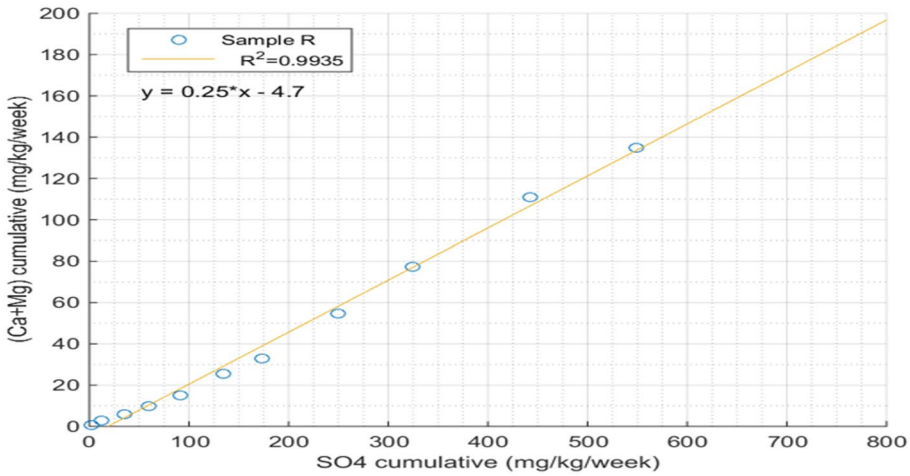

Fig. 7 Oxidation–neutralization curve for sample R

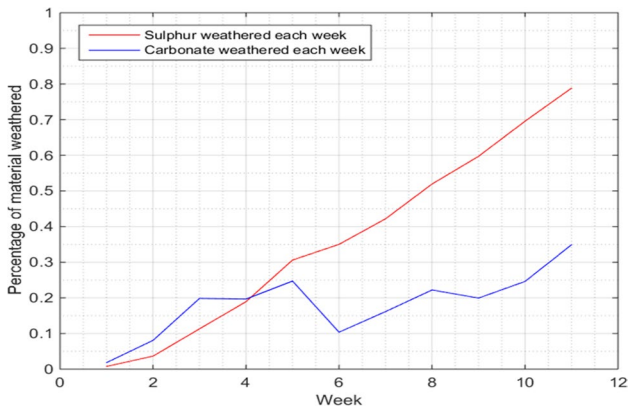

Fig. 8 Percentage of sulfur and carbonate weathered during the kinetic test of sample M

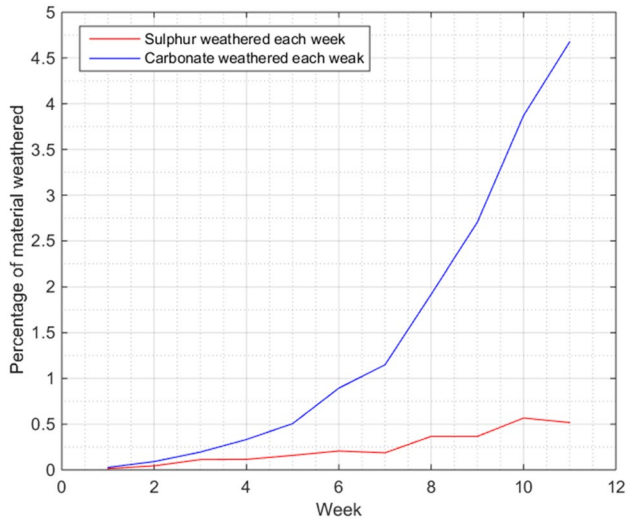

Fig. 9 Percentage of sulfur and carbonates weathered during the kinetic test in the case of sample R

Moatize, yet based on the results of this study, it can be said that there is the risk of the generation of AMD in the future when the carbonates that are neutralizing the acid are exhausted in mining company R.

Conclusions

The static and the kinetic tests were carried out using samples from the mining companies M and R in the Moatize region. The results of the static test of the sample from mining company M show that the generation of AMD there is unlikely. The kinetic test of the sample from mining company M confirms the results of the static test.

The static test of the sample from mining company R shows that AMD can be generated, and the kinetic test indicates that, as long as carbonate is available in the waste, AMD will not be generated. The kinetic test of the sample from the mining company R also shows that the weathering of the carbonate is greater and takes place more quickly than the weathering of the sulfur, which means that the carbonates will be exhausted sometimes in the future and the AMD will then be generated, since the neutralizing material will no longer be available then.

On the basis of the results of the static and of the kinetic tests, it can be concluded that there is unlikely to be any AMD generation from the tailings of the mining company M, but that there is the risk of AMD generation from the tailings of the mining company R, but only when the carbonate that is present in the material is exhausted.

Mine drainage based on the high content of sulfate and of metals is to be expected in both mines. The concentration of sulfates, of manganese, of calcium, and of magnesium in mining water is very high. These need to be removed or controlled.

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